

Twist-3 effects in polarized Drell-Yan and semi-inclusive DIS

Yuji Koike^a

^aDepartment of Physics, Niigata University, Ikarashi, Niigata 950-2181, Japan

Two twist-3 processes are discussed. We first present a simple estimate of the longitudinal-transverse spin asymmetry in the polarized Drell-Yan process. We next derive a cross section for the semi-inclusive production of a polarized spin-1/2 baryon in the DIS of an unpolarized electron off the polarized nucleon.

Spin dependent processes in high energy scatterings provide us with a possibility to extract twist-3 distribution and fragmentation functions which represent quark-gluon correlations inside the hadrons. A well known example is the nucleon's transverse spin-structure function $g_2(x, Q^2)$. In this report, we discuss two other processes in which twist-3 distribution functions reveal themselves as a leading contribution with respect to the inverse power of the hard momentum Q . The first one is the longitudinal (L) and the transverse (T) spin asymmetry A_{LT} in the nucleon-nucleon polarized Drell-Yan process. We present a simple estimate for A_{LT} in comparison with A_{LL} and A_{TT} . [1] The second one is the semi-inclusive production of a polarized spin-1/2 baryon in the deep inelastic scattering from a polarized nucleon. A formula for the cross section is presented.

In LO QCD, the double spin asymmetries in the nucleon-nucleon polarized Drell-Yan process are given by [2]

$$A_{LL}N = \Sigma_a e_a^2 g_1^a(x_1, Q^2) g_1^{\bar{a}}(x_2, Q^2), \quad (1)$$

$$A_{TT}N = a_{TT} \Sigma_a e_a^2 h_1^a(x_1, Q^2) h_1^{\bar{a}}(x_2, Q^2), \quad (2)$$

$$A_{LT}N = a_{LT} \Sigma_a e_a^2 [g_1^a(x_1, Q^2) x_2 g_T^{\bar{a}}(x_2, Q^2) + x_1 h_L^a(x_1, Q^2) h_1^{\bar{a}}(x_2, Q^2)], \quad (3)$$

where $N = \Sigma_a e_a^2 f_1^a(x_1, Q^2) f_1^{\bar{a}}(x_2, Q^2)$, Q^2 is the virtuality of the photon, e_a represent the electric charge of the quark-flavor a and the summation is over all quark and anti-quark flavors: $a = u, d, s, \bar{u}, \bar{d}, \bar{s}$, ignoring heavy quark contents (c, b, \dots) in the nucleon. The variables x_1 and x_2 refer to the momentum fractions of the par-

tons coming from the two nucleons "1" and "2", respectively. In (2) and (3), a_{TT} and a_{LT} represent the asymmetries in the parton level defined as $a_{TT} = \sin^2\theta \cos 2\phi / (1 + \cos^2\theta)$ and $a_{LT} = (M/Q)(2 \sin 2\theta \cos \phi) / (1 + \cos^2\theta)$, where θ and ϕ are, respectively, the polar and azimuthal angle of the lepton momentum with respect to the beam direction and the transverse spin. We note that A_{LL} and A_{TT} receive contribution only from the twist-2 distributions, while A_{LT} is proportional to the twist-3 distributions and hence a_{LT} is suppressed by a factor $1/Q$.

The twist-3 distributions g_T and h_L can be decomposed into the twist-2 contribution and the "purely twist-3" contribution (at $m_q = 0$):

$$g_T(x, \mu^2) = \int_x^1 dy \frac{g_1(y, \mu^2)}{y} + \tilde{g}_T(x, \mu^2),$$

$$h_L(x, \mu^2) = 2x \int_x^1 dy \frac{h_1(y, \mu^2)}{y^2} + \tilde{h}_L(x, \mu^2). \quad (4)$$

The purely twist-3 pieces \tilde{g}_T and \tilde{h}_L can be written as quark-gluon-quark correlators on the light-cone. In the following we call the first terms in (4) $g_T^{WW}(x, \mu^2)$ and $h_L^{WW}(x, \mu^2)$ (Wandzura-Wilczek parts).

For the present estimate of A_{LT} , we have used the LO parametrization by Glück-Reya-Vogt for f_1 [3], the LO parametrization (standard scenario) by Glück-Reya-Stratmann-Vogelsang (GRSV) and the LO model-A by Gehrmann and Stirling for g_1 [4]. For h_1 , g_T and h_L no experimental data is available up to now and we have to rely on some theoretical postulates. Here we assume $h_1(x, \mu^2) = g_1(x, \mu^2)$ at a low energy scale ($\mu^2 = 0.23 \text{ GeV}^2$) as has been suggested by

a low energy nucleon model [2]. These assumptions also fix g_T^{WW} and h_L^{WW} . For the purely twist-3 parts \tilde{g}_T and \tilde{h}_L we employ the bag model results at a low energy scale, assuming the bag scale is $\mu_{bag}^2 = 0.081$ and 0.25 GeV^2 . For the Q^2 evolution of $\tilde{g}_T(x, Q^2)$ and $\tilde{h}_L(x, Q^2)$, we apply the large- N_c evolution [5]: In the $N_c \rightarrow \infty$ limit, their evolution equation is reduced to a simple DGLAP form similarly to the twist-2 distribution and a correction due to the finite value of N_c is of $O(1/N_c^2) \sim 10 \%$ level.

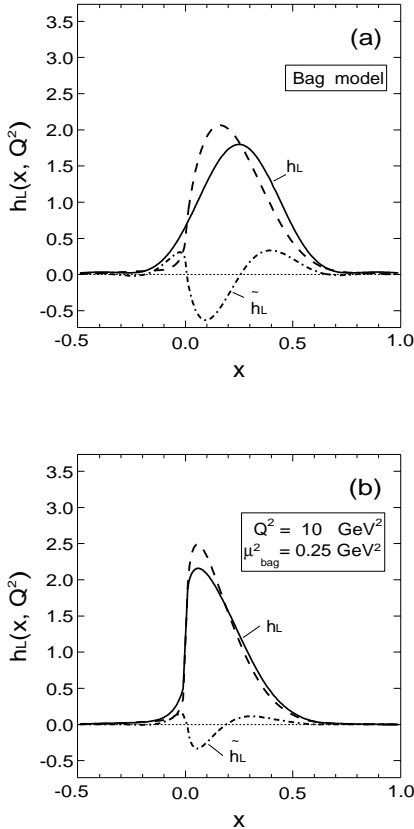


Figure 1. Bag model calculation of $h_L(x)$. The full, dashed, and dash-dot lines, respectively, denote h_L , h_L^{WW} , and \tilde{h}_L .

To see the characteristics of the Q^2 evolution of the twist-3 distributions, we show in Fig. 1 the bag model result for h_L and the one at $Q^2 = 10 \text{ GeV}^2$ obtained by assuming that the bag scale is $\mu_{bag}^2 = 0.25 \text{ GeV}^2$ [6]. One sees clearly that even though $\tilde{h}_L(x, Q^2)$ is of the same order as $h_L^{WW}(x, Q^2)$ at a low energy scale, $h_L(x, Q^2)$ is dominated by $h_L^{WW}(x, Q^2)$ at a high energy scale. This feature is common to $g_T(x, Q^2)$ and has a following general ground not peculiar to the bag model calculation:

- The anomalous dimensions for $\tilde{h}_L(x, Q^2)$ and $\tilde{g}_T(x, Q^2)$ are larger than those for $h_1(x, Q^2)$ and $g_1(x, Q^2)$, hence faster Q^2 evolution for the former.
- $\tilde{h}_L(x, Q^2)$ has a node. This is due to the sum rule $\int_{-1}^1 dx \tilde{h}_L(x, Q^2) = 0$ and $\int_{-1}^1 dx \tilde{g}_T(x, Q^2) = 0$, which is known as the Burkhardt and Cottingham sum rule for $g_T(x, Q^2)$.

In Ref. [1], we have calculated the asymmetries normalized by the partonic asymmetries, $\tilde{A}_{LL} = -A_{LL}$, $\tilde{A}_{TT} = -A_{TT}/a_{TT}$, $\tilde{A}_{LT} = -A_{LT}/a_{LT}$, at the center of mass energy $\sqrt{s} = 50$ and 200 GeV and the virtuality of the photon $Q^2 = 8^2$ and $10^2 (\text{GeV})^2$, which are within or close to the planned RHIC and HERA- \vec{N} kinematics. ($50 \text{ GeV} < \sqrt{s} < 500 \text{ GeV}$ for RHIC, and $\sqrt{s} = 40 \text{ GeV}$ for HERA- \vec{N} .) Although the GRSV and GS distributions give quite different result, the following common features are observed:

- \tilde{A}_{LT} is approximately 5 to 10 times smaller than \tilde{A}_{LL} and \tilde{A}_{TT} . This is largely due to the factor x_1 and x_2 in (3), either of which takes quite small values in the whole kinematic range considered ($-0.5 < x_F = x_1 - x_2 < 0.5$).
- The contribution from \tilde{h}_L and \tilde{g}_T is almost negligible compared with the Wandzura-Wilczek part, which is due to the peculiar Q^2 evolution shown in Fig.1. Larger bag scale μ_{bag}^2 would not make the former contribution appreciably larger.

From these results, extraction of the effect of the quark-gluon correlation in \tilde{h}_L and \tilde{g}_T would be very challenging in the future polarized Drell-Yan experiment.

Next we discuss briefly the semi-inclusive production of a polarized spin-1/2 baryon (mass M_B) in the DIS of an unpolarized electron from the polarized nucleon (mass M).^[7] In this process one can measure the following combination of the quark distribution and the fragmentation functions:

$$\begin{aligned} G_1(x, z) &= e_a^2 g_1^a(x) \hat{g}_1^a(z), \\ G_T(x, z) &= e_a^2 \left(g_T^a(x) \hat{g}_1^a(z) + \frac{M_B h_1^a(x) \hat{h}_L^a(z)}{Mxz} \right), \\ H_1(x, z) &= e_a^2 h_1^a(x) \hat{h}_1^a(z), \\ H_L(x, z) &= e_a^2 \left(h_L^a(x) \hat{h}_1^a(z) + \frac{M_B g_1^a(x) \hat{g}_T^a(z)}{Mxz} \right), \end{aligned}$$

where the summation over quark flavors is implied. Consider the cross section in the target rest frame. We take the coordinate system in which the lepton beam defines the z -axis and the x - z plane contains the nucleon polarization vector which has a polar angle α . The scattered lepton has polar and azimuthal angle (θ, ϕ) . The cross section for the production of the longitudinally polarized spin-1/2 baryon is

$$\begin{aligned} & \frac{d\Delta\sigma}{dxdydzd\phi} \\ &= \frac{\alpha_{em}^2}{Q^2} \left[-\cos\alpha \frac{1+(1-y)^2}{y} G_1(x, z) \right. \\ & \quad \left. + \sin\alpha \cos\phi \sqrt{(\kappa-1)(1-y)} \right. \\ & \quad \left. \times \left\{ \frac{1+(1-y)^2}{y} G_1(x, z) - \frac{2(2-y)}{y} G_T(x, z) \right\} \right]. \end{aligned}$$

Here $x = Q^2/2P \cdot q$, $y = (E - E')/E$, $\kappa = 1 + (4M^2x^2/Q^2)$, $z = P \cdot P_B/P \cdot q$, where $P = (M, 0)$, P_B , q are the 4-momenta of the initial nucleon, the produced baryon, and the virtual photon, and E and E' are the energies of the initial and the scattered leptons, respectively. Note the appearance of the factor $\sqrt{\kappa-1} \sim O(1/Q)$ in the second term which characterizes twist-3 effect. Even at $\alpha = \pi/2$, the nucleon's polarization vector is not completely orthogonal to the virtual photon's momentum and the cross section

receives the contribution from $G_1(x, z)$, which can be extracted by setting $\alpha = 0$.

Similarly, the cross section for the production of the transversely polarized baryon is

$$\begin{aligned} & \frac{d\Delta\sigma}{dxdydzd\phi} \\ &= \frac{\alpha_{em}^2}{Q^2} \left[-2\sin\alpha \cos(\phi - \phi') \frac{1-y}{y} H_1(x, z) \right. \\ & \quad \left. + \cos\alpha \cos\phi' \sqrt{(\kappa-1)(1-y)} \right. \\ & \quad \left. \times \left\{ -\frac{2(1-y)}{y} H_1(x, z) + \frac{2(2-y)}{y} H_L(x, z) \right\} \right], \end{aligned}$$

where ϕ' is the azimuthal angle between the polarization vector of the produced baryon \vec{S}_B and the momentum of the outgoing lepton \vec{k}' .

These semi-inclusive processes and the polarized Drell-Yan are complementary to each other to extract twist-3 distribution functions.

Acknowledgement. I thank Y. Kanazawa, N. Nishiyama and K. Tanaka for the collaboration on the topics discussed here. I'm also grateful to RIKEN-BNL center for the financial support.

REFERENCES

1. Y. Kanazawa, Y. Koike and N. Nishiyama, Phys. Lett. **B430** (1998) 195.
2. R.L. Jaffe and X. Ji, Nucl. Phys. **B375** (1992) 527.
3. M. Glück, E. Reya and A. Vogt, Z. Phys. **C67**, (1995) 433.
4. M. Glück, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. **D53** (1996) 4775; T. Gehrmann and W.J. Stirling, Phys. Rev. **D53** (1996) 6100.
5. A. Ali, V.M. Braun and G. Hiller, Phys. Lett. **B266** (1991) 117; I.I. Balitsky, V.M. Braun, Y. Koike and K. Tanaka, Phys. Rev. Lett. **77** (1996) 3078.
6. Y. Kanazawa and Y. Koike, Phys. Lett. **B403** (1997) 357.
7. Y. Kanazawa, Y. Koike and K. Tanaka, in preparation. P.J. Mulders and R.O. Tangerman, Nucl. Phys. **B461** (1996) 197.